R-64-446

A HUMAN FACTORS REVIEW OF THE AN/TSQ-47 AIR TRAFFIC CONTROL/COMMUNICATIONS SYSTEM

TECHNICAL DOCUMENTARY REPORT NO. ESD-TDR-64-446

JUNE 1964

Allen C. Busch
Robert B. King

431L/482L SYSTEMS PROGRAM OFFICE
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
L. G. Hanscom Field, Bedford, Massachusetts

System 482L

(Prepared under Contract No. AF 19(628)-439 by HRB-Singer Incorporated, State College, Pennsylvania.)

FOREWORD

This technical documentary report is HRB-Singer report No. 353-R-6. It constitutes the sixth and final report in a series of reports resulting from HRB-Singer's human factors efforts on Contract No. AF 19(628)-439, in support of the AN/TSQ-47 Air Traffic Control/Communications System.

This work was performed for the 431L/482L Systems Program Office, Electronic Systems Division, United States Air Force. Actual effort was carried out at Fort Dawes, Winthrop, Massachusetts.

A HUMAN FACTORS REVIEW
OF THE AN/TSQ-47
AIR TRAFFIC CONTROL/COMMUNICATIONS SYSTEM

ABSTRACT

Category I testing has recently been completed on the AN/TSQ-47 Mobile Air Traffic Control/Communications System. This report presents a review of human factors problems which occurred during the Category I testing phase and in prior development phases of the system. The design changes suggested are based on recommendations made prior to the completion of Category I testing for the purpose of outlining tentative system deficiencies. Each shelter is reviewed separately, and problems common to all system facilities are discussed. The major topics of review are the operational considerations for each shelter, the working environment, and the design of consoles and work places.

REVIEW AND APPROVAL

This technical documentary report, ESD-TDR-64-446 has been reviewed and is approved.

B. F. Green, Jr.
Technical Contract Monitor

Approved:

Dr. R. E. Stover
Director, Behavioral Sciences Laboratory

KEY WORD LIST

1. Communication Systems
2. Control Systems
3. Air Traffic
4. Radar
5. Design
6. Human Engineering
7. Human Factors

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

SECTION 1

INTRODUCTION

This report is intended to provide a human factors review of the AN/TSQ-47 Air Traffic Control/Communications System. A thorough review could be done only after Category II and III testing. At the writing of this report, only Category I testing is nearing completion: therefore, much of what is reported herein is a result of data gathered during the fabrication and initial testing of the system.

Volumes of data pertaining to human factors criteria and design standards are available. To arbitrarily apply these standards to a system, however, would be like evaluating it in a vacuum. Equipment should be evaluated in relation to its design requirements. Some of the requirements for the AN/TSQ-47 call for modification of human engineering design standards. These system requirements include such things as:

1. The system is a quick-reaction emergency support system.
2. The system must be air transportable with minimum weight and limited volume.
3. The system was assembled from "off-the-shelf" equipments.
4. The system must increase the terminal control area capacity over that offered by current systems.

Under these circumstances it was not feasible to design all the comforts of a fixed installation into a mobile emergency system. Even though the system is comprised of "off-the-shelf" equipment, the integration and arrangement of equipment, personnel, and procedures create a totally "new" man-machine environment. Under these circumstances new testing procedures and new testing criteria need to be developed to conduct a reliable and valid test of the system. Too frequently personnel with "old" operational and maintenance skills are employed to man a "new" system during the initial category testing programs without receiving proper training and orientation.

The authors are well aware of numerous changes that could be suggested as human factors modifications. Those presented here, however, are only based upon tentative system deficiencies outlined as a result of Category I testing. Additional items will more than likely be generated during the Category II and III tests to be conducted at a later date at Eglin Air Force Base, Florida.

Another function that this report will serve will be to call attention to several seemingly insignificant problems in equipment design which may not have been voiced before. It is difficult to be insistent in regard to minor equipment design aspects when more grave functional problems demand engineering attention. For example, it is difficult to worry about the design of a radio control panel when reception on this radio is not intelligible. As a result, minor objectionable design aspects are often not mentioned until most of the major so-called "operational" problems are solved. This in itself is regrettable, but what is even more regrettable is that distinctions are drawn between what are termed "operational problems" and "human engineering design problems." Design aspects of this latter nature are often viewed as "frosting on the cake"--nice to have, but not really necessary for effective system performance. In some cases this is true, but in many cases it is imperative that careful consideration be devoted to such aspects. This is due to two factors:

1. As system equipment sophistication increases, so do operational requirements. If the operational requirements exceed those which the given personnel are capable of meeting, the increase in system equipment sophistication will be in vain. If this point is reached, the frosting on the cake becomes as essential as the cake itself; and it is meaningless to speak of a hierarcy of design problems with some problems being more important and, hence, requiring solution before others can be seriously considered. An individual piece of equipment may be functioning; but when the total demands of the operator are considered, this unit of equipment may be rendered just as nonfunctional as if it were not in operating condition.

2. Unless detailed, controlled performance tests are made on man-machine complexes it is difficult to determine which design aspects are highly significant and which are not. Certainly, every effort is made to maximize system performance by giving careful consideration to design variables known to have a large effect on human performance. Variables interact, however, and

the relative importance of any one variable may change significantly when others are present. When the man-machine system becomes complex, the exact effect of particular design and environmental variables is not fully known in some cases. What may appear to be a rather insignificant aspect may take on a much greater magnitude of importance. It is thus important that all variables be analyzed.

SECTION 2

AN/TSW-5 AIR TRAFFIC CONTROL CENTRAL

The AN/TSW-5 functions as the terminal area control center facility for the AN/TSQ-47 System. It provides the system with the means for exercising positive air traffic control within a large terminal area and precision control of final approaches to a single base. The AN/TSW-5 receives search radar and SIF beacon video data from the AN/TPS-35 and precision approach radar data from the AN/TPN-14 via microwave link or cables. It provides air-ground-air communications to enable the controllers to communicate with arriving and departing aircraft. It provides ground communications for the controllers to communicate with personnel in all the other shelters for effective ground coordination.

This shelter is designed to accommodate a maximum of nine controllers for maximum system loading, or as few as two or three controllers during minimum air traffic or system load. Figure 2-1 shows the relative positions of the nine controllers. A conference-type PPI is provided and the arrangement of all operational controls allows for efficient traffic flow and operational control from maximum to minimum loading. This is a new control arrangement that in early studies indicated a very favorable flow of information between all operational functions necessary for the control of inbound and outbound aircraft in a terminal control area. During the Category I performance and acceptance test, it looked favorable. The system testing during Category II and III Tests should provide more positive data concerning the adequacy of this type of arrangement of men and equipment. Since there are new operational concepts for the operations of this shelter, the operational testing needs to be geared to these concepts rather than to old operating modes. Also due to these new operational concepts and equipments, it was to be expected that certain shortcomings would be highlighted during the initial testing. The following comments are intended to illustrate how this shelter might be improved from a human factors standpoint as a result of information and experiences gathered since the writing of the initial equipment specifications.

The communications selector panels located at each of the nine operational positions have excessive illumination and can cause poor and erroneous operations. The illumination from the indicator for the rotary selector switch is much too

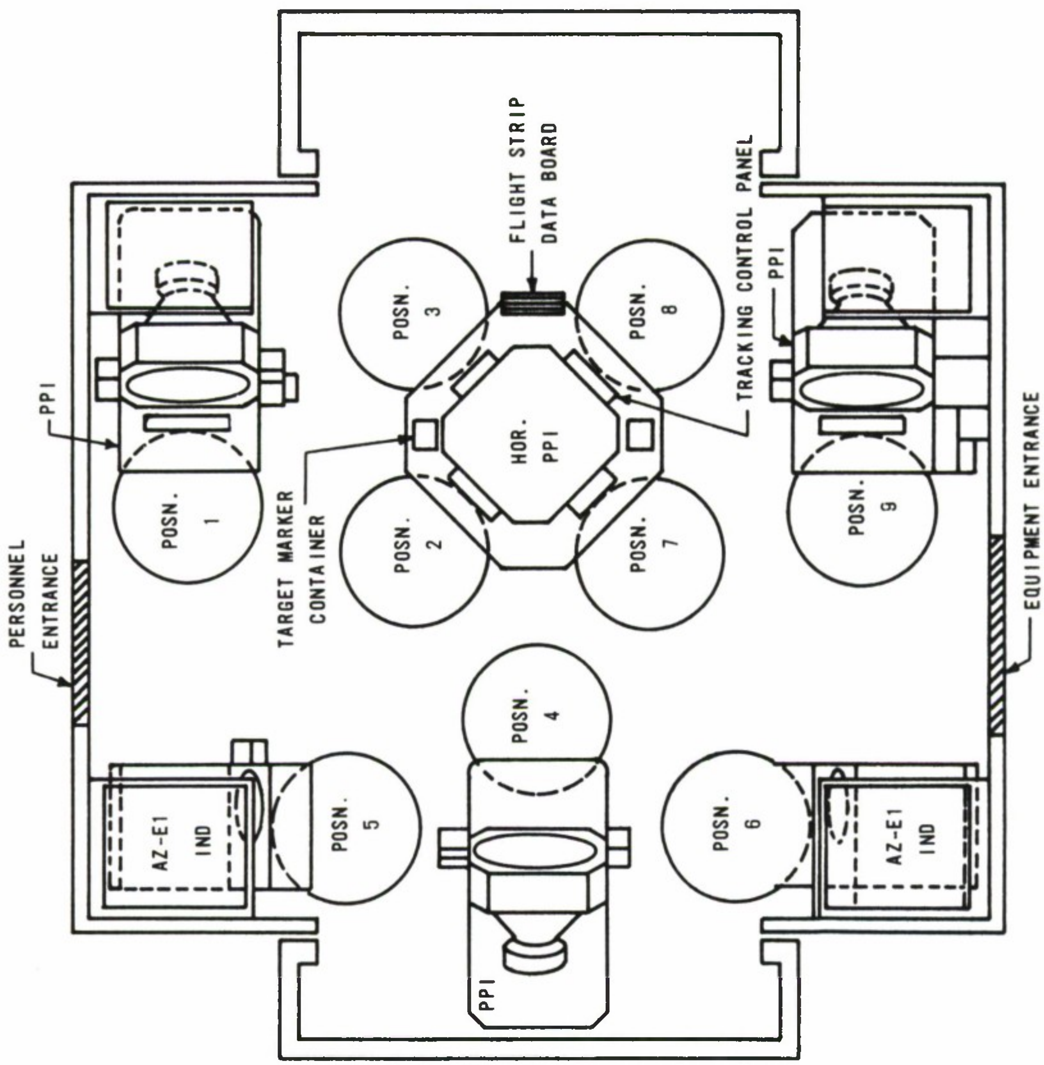


FIG. 2-1 PLAN VIEW, AN/TSW-5

intensive. This indicator can cause: (1) excessive eye fatigue; (2) loss of dark adaptation; and (3) deleterious reflections, which render the operator unable to detect minimum radar returns. The intensity of any operating light should not exceed 10 times the intensity of a weak radar return. The other indicators on this panel are not such as to be excessively annoying, but do cause reflections in the scope faces that can cause poor tracking or failure to observe a weak target. The level of illumination from the greens and blues is only 3-10 percent of the level of the yellows. Since the use of colored lights[1] on this panel is of dubious value, and to control a uniform intensity level of all the various colors from a single control is difficult, it is recommended that dimly-lit yellow or white indicators be used for the complete panel. In some cases, such as the control panels over the horizontal scope, it may be necessary to provide shields or a ridge on the bottom of the indicator panel to prevent these indicators from reflecting in the face of the scope.

The method of displaying the frequency allocators in the above indicators is crude. The negatives with the frequency do not stay in the provided slots very well and considerable light leaks out around the negatives. There are several different types of illuminated indicators on the market that "open" from the front panel so that plastic cards for the display of information can be removed or changed.

The location of the 24-hour clock within the shelter makes it directly visible to only about two of the nine operators. There is probably no one position within the whole shelter where all the operators could view it satisfactorily. The best solution would be to provide small 24-hour numeral read-out clocks at each operator position with the numbers being internally illuminated.

The intensity of the amber indicators on the micro-wave racks are such as to cause deleterious reflections in the PPI at Position 4. It is recommended that these be shielded and/or reduced in intensity.

---

[1]Mil Std. 803, Para. 6.1.3.10 states: "Use lights and all other indicators sparingly. Be sure that the indicator displays information necessary to effective system operation.

The specification requires that the target markers (shrimpboats) fluoresce under ultraviolet light. The present markers do not fluoresce adequately. There appears to be no increase in their visibility with the ultraviolet lamp on. There are several paint products on the market that can be applied to plastic to make it fluoresce. There should be no physiological problems associated with the use of this ultraviolet projector. Data indicate that the lamp with a #31 ultraviolet filter has a band width of essentially 330-400 m(millimicrons). This is generally considered to be within the blacklight region (300-400m) which is above the erthemal, bactericidal, and ozone regions.

The scope height, shelf height, and accessibility of controls for the Az-El scopes are considered to be problems. Due to the contractor's increasing the height of the base for these scopes, it raised the whole Az-El scope. This scope and the housing are about 4-5 inches too high. The scope, as designed for the AN/TPN-14, is very adequate. The shelf height should be 29-30 inches from the floor, and the center of the CRT should be perpendicular to the line of sight of the 50th percentile military operator.

The tracking acquisition device (light gun) at Operator Positions 1 and 9 is difficult to reach. The holder for the light gun is so positioned that to retrieve and return the light gun, it is necessary to stretch over the writing shelf and practically lose sight of the scope face. Since the light gun is used for the acquisition of each target, it is used frequently. Space for attaching equipment to the side of the PPI is at a premium. The most practical solution would be to lower the land line box and attach the light gun holder where the land line box is presently located.

Optical projectors are used at the horizontal scope (positions 2, 3, 7, and 8) and Operator Position 4 to provide auxiliary data to these operators. Data from these projectors cause an image to be reflected both from the scope surface and the face of the implosion shield. The scope face and the implosion shield are approximately 1-2 inches apart. These dual reflections cause considerable compounding of the projected data. It is recommended that the distance between the implosion shield and the scope face be decreased and the implosion shield be coated with an anti-reflection coating material.

The feeder controller (Position #4) uses the information provided by the track-symbol group. There are no tracking controls at Position 4. When this operator is finished using the alpha-numeric track, he has to coordinate

the repositioning of the track to hangar position with one of the operators at the horizontal scope. This is an unnecessary coordinating function. It would be desirable to have the track return to hangar automatically after it reaches a specific point in the arrival or departure phase of flight. An alternative suggestion would be to provide the feeder controller with controls for the track symbol group and thus he could return the track to hangar himself.

One of the uses of the alpha-numeric symbol trackers is its function as a hand-off device between controllers within the RAPCON. A second device, frequently employed, is the use of flight data strips which are passed from one controller to another as a hand-off is initiated. A third technique would be simply for one controller to verbally notify the other controller that a hand-off is imminent. None of these techniques is readily available for the hand-off between the feeder controller and the final controller (PAR operator). No track-symbol information is available to the final controller. No conventional flight data strips are employed in this shelter. The noise level within this shelter and the distance between the feeder and final controller make reaching and person-to-person communication difficult. Because of this difficulty, it is recommended that the alpha-numeric track information be transferred to a fixed position on the scope of the appropriate final controller.

The operating controls for the PPI scopes are located under plastic covers. The general shape of these covers and the distance of the control knobs from the surface make manipulation of them difficult. Also, the design of the catch for these spring-loaded doors is such that they are not easily opened and closed.

The design of the heating and ventilating system is such that there is uneven cooling of the shelter, especially at Operator Positions 4, 5, and 6. There is likely to be a difference of 10° F. between the air temperature at the operator's head and the air temperature at his feet. In all probability, the operator will feel a cool draft on his neck and head, whereas his feet will feel hot in comparison. A general redesign of the air distribution system would be necessary to remedy this situation.

In the A/G/A shelter, the changing of the VHF filter couplers is very difficult due to the high torque on these tuning shafts. A higher gear ratio should be used to ease the turning of the frequency adjustment crank. Another solution would be to provide a crank with a bigger knob and an increased radius of motion.

SECTION 3

AN/TSW-6 AIR TRAFFIC CONTROL CENTRAL

The AN/TSW-6 Air Traffic Control Central is an air traffic control tower designed for mobile operation. The facility is equipped with four VHF transceivers, five UHF transceivers, and one HF transceiver, providing a total of ten audio channels. Aircraft control will be conducted from this facility under VFR conditions, and the facility will serve for control of ground traffic and for flight coordination during IRF conditions. The facility contains work stations for three operators--an area controller, a data man, and a ground controller. Figure 3-1 shows the relative positions of these three operators. Other operations equipment includes local weather measuring equipment, a direction finder, a light signal gun, and three inter-shelter communication units.

Shelter design in the present AN/TSW-6 facilities appears to be good for the most part. Many problems have been resolved in the development of this shelter. A few problems remain, however, and these are discussed in the following two subsections.

1. PERSONNEL SAFETY

One persistent problem in the design of this facility concerns the safety of the personnel who will be working with the shelter. The present facilities are designed to be raised four to six feet above ground level for operation. Several safety hazards exist in conjunction with the ladders and catwalk on the shelter. The catwalk sags on the outer edges by as much as six inches from the horizontal with a man's weight. The stanchions for the handlines give or move considerably when leaned against, and thus provide little support when relied upon. This sagging of the catwalk and nonrigidity of the stanchions could cause a person to lose his balance and fall. It is also indicative of poor structural support, and these parts could conceivably give way completely. It is recommended that these parts be reinforced and strengthened and that the handline be tightened and secured to provide reliable support if needed.

The ladder leading from the ground catwalk presents somewhat of a safety hazard due to the design of the steps and the angle of ascent. The existing ladder is of approved design for a ship's ladder; but in this application, the design seems to be unsatisfactory. If storage space will permit, the best solution would be to decrease the angle of the ladder so it would be classified as stairs and not a ladder as it is now. This would involve lowering the angle of

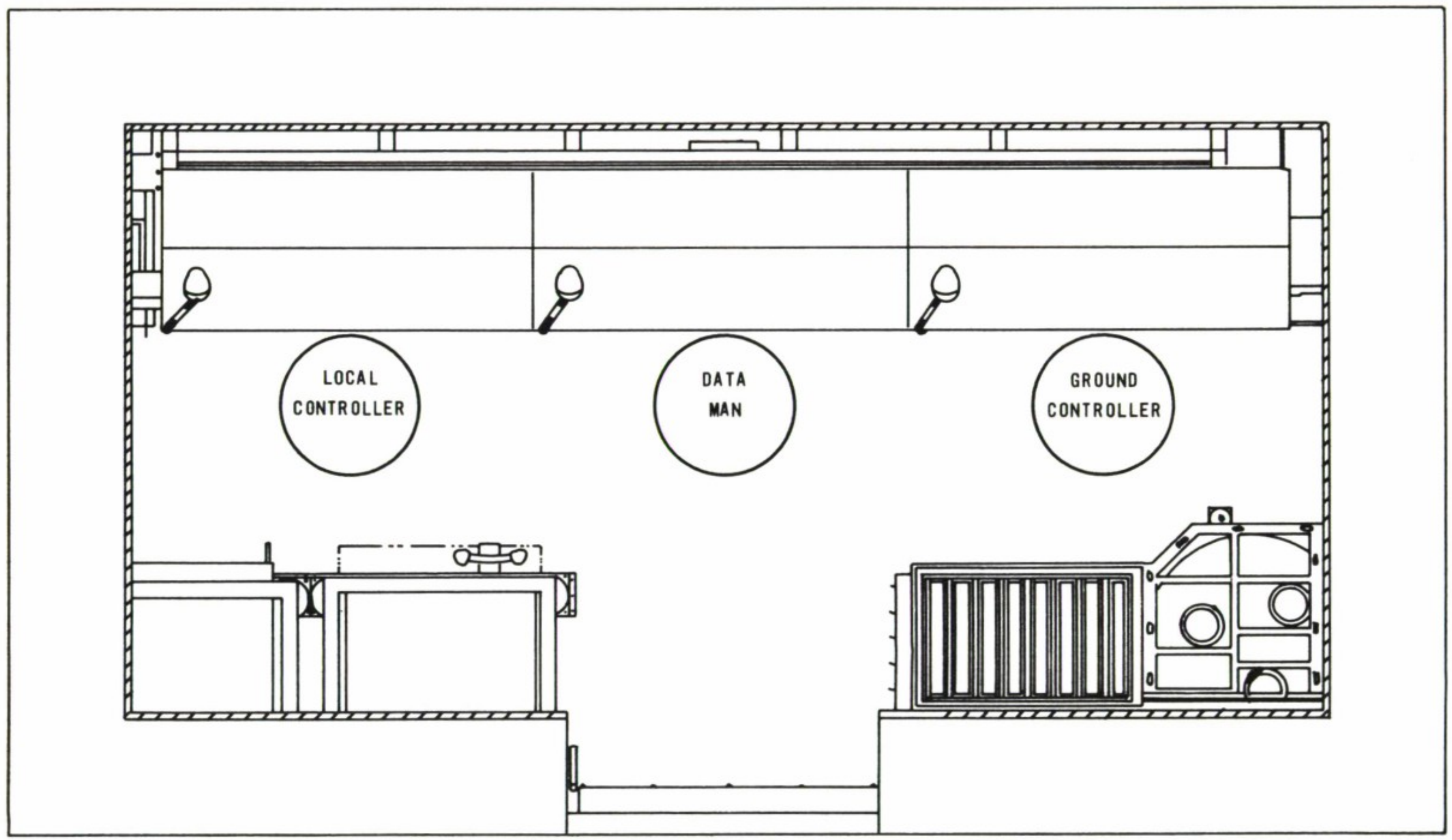


FIG. 3-1 PLAN VIEW, AN/TSW-6

ascent to 30 to 45 degrees, increasing the tread depth to 9 to 11 inches, and providing a step rise of 7-8 inches. If a ladder is deemed necessary, the distance between rungs should be approximately 12 inches.

The ladder leading from the catwalk to the roof presents a safety hazard due to the fact that the left-side rail protrudes above the level of the roof. The best solution here would be to redesign the ladder so that the left rail curves over in about a 12-inch arc and refastens to the roof. A simpler and acceptable solution would be to cut off the protruding portion of the rail so as to make it flush with the top mounting bracket on that side of the ladder.

2. WORKPLACE, CONSOLE, AND RELATED EQUIPMENT DESIGN

Operator workspace is restricted in this facility in terms of depth of operator-seating area and aisle space for moving around. This problem is not considered serious, however, since the door is easily accessible and operations within the shelter will require very little operator movement in the aisle. Seating space is restricted from the optimal but considered adequate for acceptable facility operation.

Tower operations require that a clock be readily available to controllers. The clock in the AN/TSW-6 is both poorly positioned and poorly illuminated for efficient use. It is recommended that small, digital read-out clocks be provided at each operator position. These clocks should be mounted in the individual control panels and should be internally illuminated with white light.

Design of the console drawers is poor and modifications are recommended. The existing drawer is difficult to open because of poor suspension and a turn-to-latch handle which is hard to turn. The drawer is too small to be of practical use. The drawer should be large enough to accept a standard 8-1/2 by 11 paper tablet and should have larger turn-knobs for opening.

Design of the light signal gun mounting is also poor and modifications are in order. Removal, sighting, and returning the gun to its mounting bracket promise to be quite time-consuming and difficult with the current design. It is necessary to pull a locking pin to release the gun and to reinsert this pin when the gun is to be mounted. Replacing this pin will be quite difficult at night because of poor lighting for such an operation. In addition, the gun is mounted too high for approximately 60% of the using population to reach. One has to

reach both up and over the console to get the gun and pull the release pin. The gun should be designed for one hand release and operation. This would require a spring-loaded retraction cable strong enough to support the gun at any position of use.

Two additional problems arise in regard to the console lighting in the AN/TSW-6. The first problem concerns the red lamps used to provide general console and data rack illumination. These lamps have adjustable intensity; but due to their positioning, the operator at the data position will either have difficulty reading data on the flight data rack or else there will be excessive light, producing glare, and impairing the operational efficiency of the local and ground controllers. It is recommended that the lights illuminating the data rack be redesigned to cast light more directly on the data rack and less on surrounding areas. The shades should be so designed as to prevent viewing of the lamps from the local and ground positions. The second problem concerns the speaker modulating indicator lamps, the channel in-use lamps, and the transmit lamps. These lamps are all very directional and cannot be seen from adjacent operator positions when at maximum intensity during daylight. This is especially serious in the case of the modulating speaker lamps since controllers will rely on these lamps to aid them in distinguishing which speaker is in use. Under daylight conditions the white lamps designating VHF Channel 2 cannot be seen from <u>any</u> position. The lamps are simply not bright enough. Recommendations for improvement are as follows:

1. There seems to be little value to the current practice of color coding these lamps. As a matter of fact, the color coding only seems to lend confusion to the identification of radio channels. The different colored lamps produce different degrees of intensity and make identification even more difficult. It is therefore recommended that all IN-USE indicator lamps in the shelter be either amber or white in color.

2. Intensity is currently adjusted at each individual lamp by opening or closing a small aperture enclosed within the lamp. This mechanism produces many of the objectionable directional properties of the lamps. If all lamps were the same color, a central rheostat could be used at each operator position for adjustment of intensity,

and the lamps could employ a diffusing lens cap to provide more even distribution of the light.

3. If the color coding is discontinued in regard to the lamps, it should also be discontinued in regard to the communications selector switches. Color coding is used on these switches to designate channels normally used at particular operator positions. Again, it appears to be of little value. It is recommended instead that the switches be numbered and labeled according to associated channel usage (VHF 1, UHF 2, etc.) and, also, that they be labeled and grouped according to the operator position at which they will normally be used. (For example, the UHF and VHF channels normally used for local control should be labeled LOCAL.)

SECTION 4

AN/TPN - 14 RADAR SET

The AN/TPN-14 (Precision Approach Radar Shelter) is designed with two operator positions--one, a final approach position and the second, a maintenance repair area. This shelter is designed for precision approach control of all types of aircraft providing to the controller the range, azimuth, and elevation of aircraft in the final approach phase of flight. A microwave link and remote cabling provide the means of relaying the information to the Air Traffic Control Central AN/TSW-5. In the event of a failure in this relaying equipment or in the TSW-5, this shelter can operate as the control function for the final approach phase of flight.

The general layout (see Figure 4-1) of this shelter provides more room and satisfactory operating/maintenance operations than any other shelter in the system. However, there are a few areas that could be improved from the human factors point of view.

With the location of the maintenance repair bench and the location and design of the ventilation system or air plenum, it is likely that the repairman, while sitting at the repair bench, will feel an uncomfortable draft on his face and head. It would be necessary for the repairman to work at the extreme right of the work bench to avoid the draft. A better solution would be to move the plenum chamber forward and down from the ceiling, thus allowing a greater portion of the air flow to be directed toward the microwave rack rather than towards the work area.

When it is necessary to perform maintenance checks on the control indicator or maintenance checks of the radar transmitter/receiver, it is necessary to unbolt the assembly from the floor or unbolt the CRT section from the base. These bolts are not readily accessible. It will be necessary to put the indicator in the vicinity of the work bench while performing maintenance checks. A more desirable solution would be to have the whole indicator assembly on locking casters. It would then be much more accessible for maintenance. Troubleshooting with the indicator could be done while it is sitting on the base section. In other words, the base section could be used as a dolly while troubleshooting the equipment.

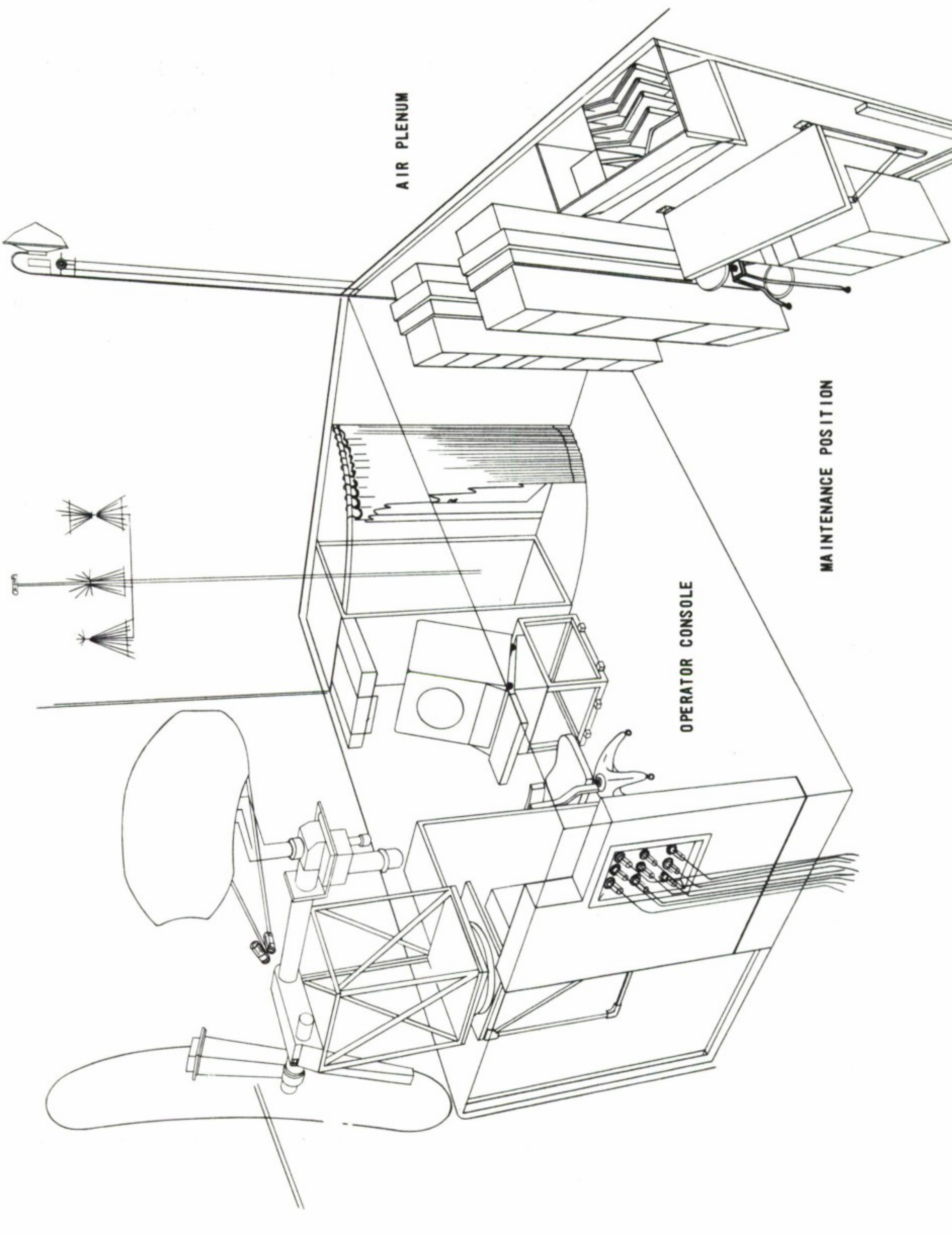


FIG. 4-1 ISOMETRIC VIEW, AN/TPN-14

It would be desirable to have the radar polarization function controlled from within the shelter rather than at the antenna. The polarization is most frequently changed from linear to circular when the weather becomes inclement. Thus, the operator, under the present design, has to climb onto the shelter roof to change the polarization. It would be very advantageous to the operators to have this function remoted to either the control indicator or to the transmitter control panel.

On the Power Distribution Panel, the labels are in some places below, and in other places above their respective receptacles. It would be desirable to have all of them consistently above or below the receptacle--preferably above.

Several controls on the operator console should be modified to improve the operation and reduce the probability of operator error. The High Voltage switch on the indicator must be in the OFF position when changing pulse width to keep from blowing fuses. In order to insure that the High Voltage switch is thrown first, these two switches should be linked mechanically so that the pulse width cannot be changed until the High Voltage is turned off. The next best solution would be to use the existing switches but put a clearly legible WARNING plate next to the Pulse Width switch. It is realized, however, that the Pulse Width will not be changed very often, but when the Pulse Width is changed, it will cause the fuses to blow, thereby putting this radar off the air until they are replaced.

It is not clear how the EL TARGET control on the operator console is to operate. It would be desirable to have it marked with arrows to indicate the direction of movement.

The design of the air plenum with the acoustically-treated vanes inside appeared to do a satisfactory job of attenuating the blower noise and air velocity noise from the air conditioners. This type of design could possibly assist the noise attenuation in the other shelters.

SECTION 5

AN/TSC-23 COMMUNICATIONS CENTRAL

The AN/TSC-23 is a long-range, point-to-point communications facility employing cryptographic and clear teletype and voice-radio communication modes. The shelter is equipped to accommodate five operating personnel if necessary. When fully manned, the crew would consist of a switchboard operator, two crypto-teletype operators, and two clear teletype operators--one of whom would serve in a supervisory capacity for the purpose of assigning responsibilities and routing messages.

Figure 5-1 shows the relative positions of the operators and the four teletype stations. Each teletype machine includes a keyboard, a punched tape distributor, a page printer, and a tape perforator/writer, and is capable of full duplex operation (i.e., each machine can send and receive simultaneously). There are three HF channels in the communications shelter. Each HF channel is divided into four different audio channels, providing a total of twelve audio channels. Since one HF channel (four audio channels) normally serves as a backup, the operational capability consists of two HF channels (eight audio channels).

The AN/TSC-23 communications facility has been the subject of controversy due to the design of the facility itself and the communications capabilities afforded by the facility. In addition, several human engineering problems can be found in the existing design which bear mentioning. In the following discussion, the problems and controversial issues have been reviewed simultaneously.

1. ENVIRONMENTAL ASPECTS

a. Noise. From a human engineering standpoint, there has been one outstanding problem associated with this shelter throughout its development. This has been the ambient noise produced by the air conditioning and communications equipment which are a part of the facility. Since ambient noise is a problem common to most of the shelters in the TSQ-47 system, it has been treated in a separate section (Section 6) in this report. It bears mention here, however, since the problem is most acute in this shelter. It is ironic that the shelter serving as the communications center for the system has the highest

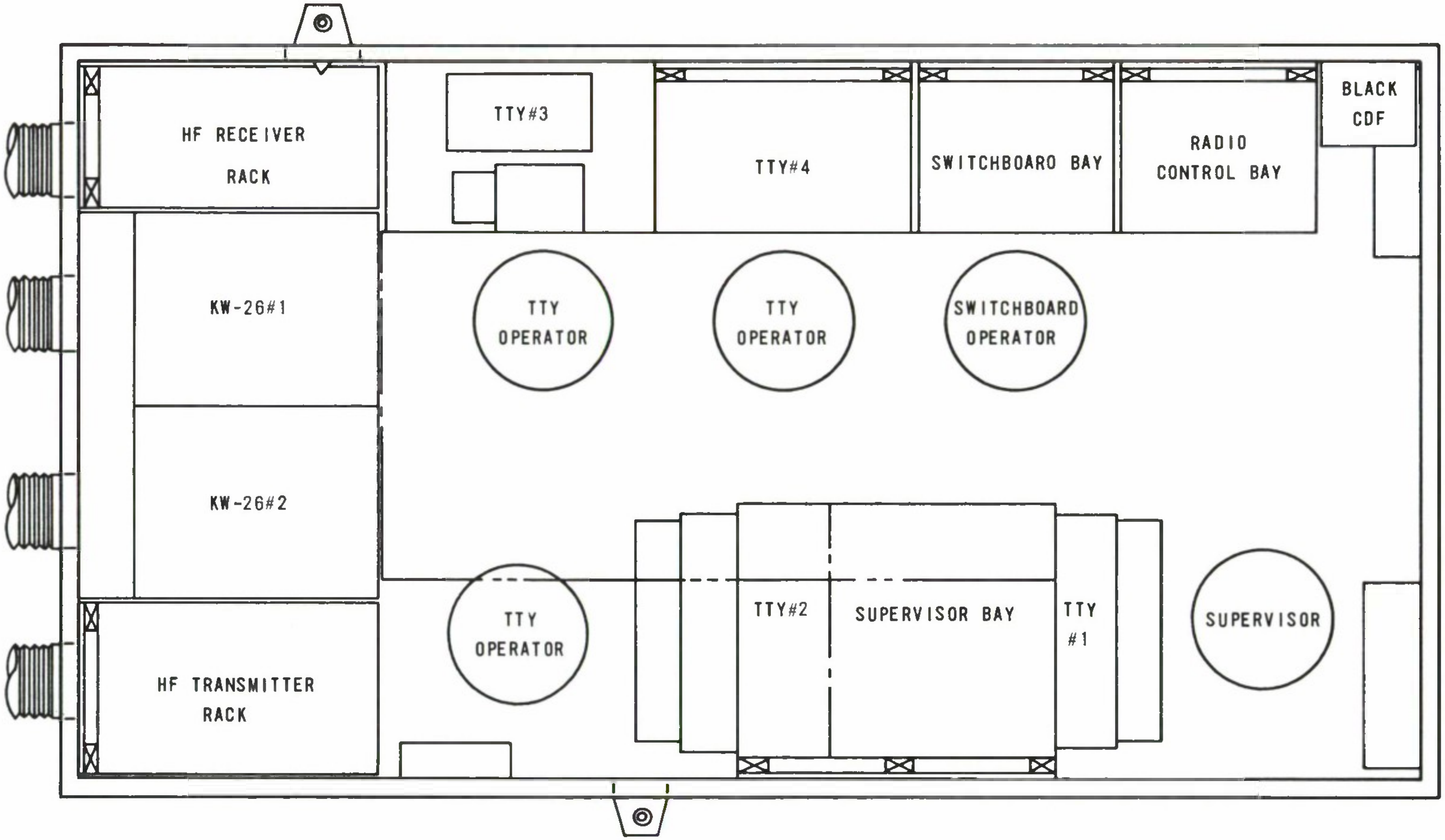


FIG. 5-1 AN/TSC-23 PLAN VIEW

degree of ambient noise. Verbal communications, more than any other operator function, require controlled noise environments. Suggestions for reducing the noise are given in Section 6.

b. Illumination. Visual tasks performed in the TSW-23 are not as demanding as those performed in shelters containing radar equipment. Nevertheless, the illumination in the facility must be designed with care to insure adequate workplace lighting with a minimum of glare. Workplace lighting seems good in terms of adequacy of illumination. Adjustable lamps are provided at each teletype station, and two rows of ceiling-mounted lamps provide a high level of general illumination throughout the shelter. There appears to be a problem of glare as a result of these ceiling-mounted lights, however. This is direct glare produced from having an unshielded incandescent light bulb within the field of vision. These ceiling-mounted lights are frosted for glare prevention, but additional precautions appear to be warranted. The bulbs should be covered with adjustable shields similar to those used in the AN/TPN-14 radar facility. Through the use of such shields, lamps producing glare at particular operator positions could be either dimmed or directed toward other surfaces without seriously reducing the total shelter illumination. The shelter has sufficient illumination to allow completely indirect lighting if necessary.

The adequacy of environmental illumination is a function of the nature of the light sources and the reflective characteristics of the shelter interior and equipment surfaces. Different colors and surface textures have different capacities for reflecting and distributing or diffusing light. While the relationship of illumination and color is a field of study too broad for detailed discussion in this report, one important aspect requires mention. The contrast of equipment color with the color of background surfaces (walls, ceiling) has direct bearing on the adequacy of illumination for certain tasks. Problems of visual accommodation and pupil constriction arise when the region surrounding a task area is lighter or even the same as the task area. When the task area is dark and the surrounding area relatively light, the eye will not rapidly accommodate to the darker surfaces, and a loss of visual acuity will result. Furthermore, it may be necessary to raise the level of illumination to compensate for task areas containing equipment that is a dark color and thus produces unnecessary glare and excessive brightness.

The equipment racks and panels in the TSC-23 are painted semigloss black and the walls and ceiling are light grey. Equipment racks and panels are traditionally painted black in radar control facilities because low reflectance is essential for CRT viewing.[1] Also, in CRT viewing, the scope is always lighter than the surrounding equipment, therefore justifying the black equipment panels. In a facility such as the TSC-23, however, these requirements do not hold and black paint is unsuited for use on equipment racks and panels for the following reasons:

1. It does not provide adequate reflectance of light for even shelter illumination and perception of equipment detail, thus creating lighting problems.
2. It has too great a contrast to the surrounding areas, thus requiring excessive time for visual accommodation.

More acceptable colors for equipment racks and panels in this shelter would be medium gray and medium green in a lusterless texture. MIL-STD-803(USAF), the military standard concerned with human engineering criteria for aircraft, missile and space systems, and ground support equipment appears to be applicable to this facility;[2] and the following color scheme would be recommended.

---

[1]Recent studies indicate that black equipment is not essential even for CRT operations, provided low reflectance is maintained. Colors other than black are preferable because they permit easier perception of equipment detail.

[2]While applicable to this situation, this specification was not intended to cover all situations. It is not applicable, for example, to radar equipment or any other equipment where dark adaption and perception of minimum intensity signals are necessary.

Area	Color	Number	Reference
Ceilings	Lusterless White	37886	FED-STD-595
Walls	Lusterless Green	34670	FED-STD-595
Equipment Racks, Storage areas	Lusterless Green	34300	FED-STD-595
Floor	Lusterless Gray	36440	FED-STD-595

c. Ventilation, Heating, and Air Conditioning. In spite of the criticism directed at the TSW-23 for inadequate air conditioning, any problems that exist in this respect are a function of the design and area of the ceiling plenum chamber and the general air distribution system within this shelter. Operators working in the shelter have complained of an excessive and annoying draft directed at their heads when they are standing. While a problem exists, it is not considered serious for the following reasons. Complaints were made under test conditions. The operators were standing much of the time because there was a constant flow of traffic through the shelter for maintenance, alignment, and data-taking tasks. This is not likely to be the case during field operations. Also, the louvers on the plenum chamber were not adjusted properly for operation. The louvers are adjustable only with a small tool which invariably could not be found during test operations. During tests no one operator was present at a particular work station long enough to become sufficiently motivated to find the tool and adjust the captive adjustment tool fastened to the louvers or to an equipment rack where it would be easily accessible. In future facility designs, it would be more desirable to design the louvers so that they might be adjusted by hand and eliminate the need for such a tool.

The cooling capacity of the two air conditioners serving the shelter is probably adequate, and most of the criticism concerning the cooling capacity was based on incorrect thermal data on both the shelter and the air conditioners. Each air conditioning unit has a rated cooling capacity of 35,200 BTU/hr. Two conditioning units are used with the TSC-23 producing a total cooling capacity

of 70,400 BTU/hr. Total heat gain has been computed as 70,620 BTU/hr.[1] On the basis of these two figures, the adequacy of the air conditioner cooling capacity would certainly appear to be borderline. The figure of 70,620 BTU/hr. total heat gain, however, is computed from a hypothetical case in which all shelter equipment is in operation and all five operating personnel are present. One-third of the radio equipment in the facility represents backup capability, and it is not part of the operational philosophy of the facility to operate all three transceivers and their related equipment simultaneously. This being the case, the total heat gain attributed to shelter equipment can reasonably be reduced by a factor of nearly 20%, and the total heat gain of the facility would be approximately 66,850 BTU/hr. -- well below the cooling capacity of the two air conditioners.

Shelter ventilation also appears quite adequate in the TSC-23. Again, criticism seems to be due to erroneous data and the use of nonapplicable standards. Airspace of 200 cubic feet per person is considered necessary for physiological functioning in a work situation in general industrial construction. Such an air space is only necessary, however, if no steps are taken to circulate fresh air or chemically purify recirculated air. When such steps are taken, there is no firm requirement for airspace. Indeed, divers are able to function physiologically in an environment having <u>no</u> "airspace." Supply of adequate ventilation in a small enclosure or a transportable shelter depends primarily upon the oxygen supply, air temperature, air pressure, and humidity requirements of the occupants. Each operation requires 4 to 6 cubic feet of fresh air per minute to prevent the accumulation of a detrimental amount of carbon dioxide. Requirements for maintaining effective levels of temperature and humidity dictate air exchange at the rate of 25 cubic feet per minute. The air conditioners serving the TSW-23 shelter are each capable of supplying outside air at a rate of 75 cubic feet per minute--- thus the total requirement of 125 cubic feet per minute is adequately met.

---

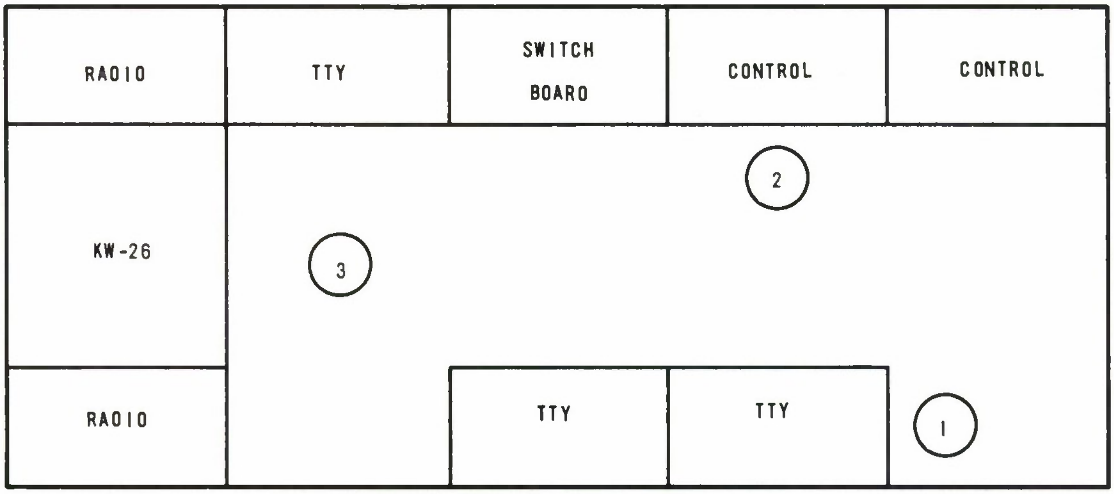
[1]RCA Human Engineering Report No. 3. Report No. CR 63-548-20.

2. EQUIPMENT CONFIGURATION AND MANNING REQUIREMENTS

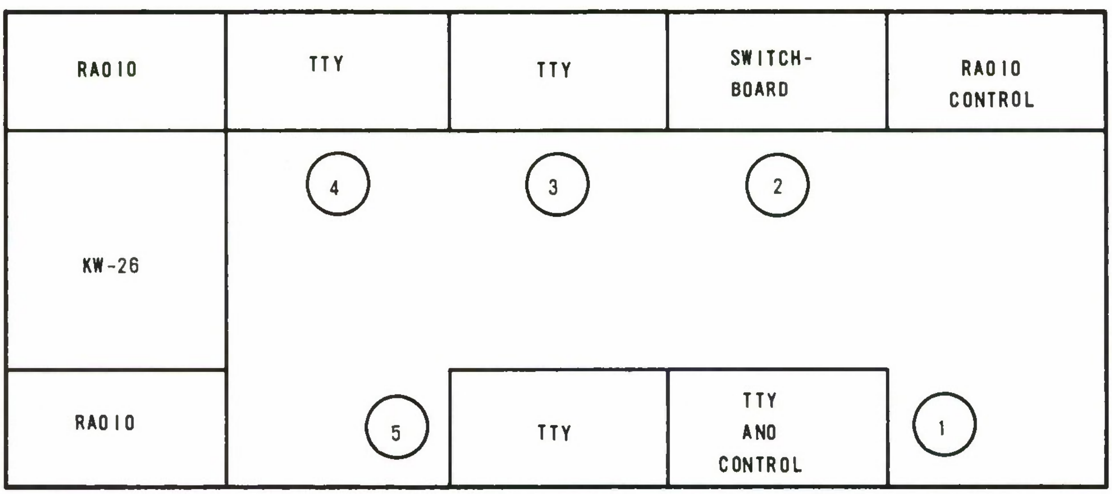
Considerable criticism has been levied against this facility in regard to the number of operator positions and the configuration of these positions. Although the criticism was undoubtedly prompted by good intentions, it is, for the most part, unjust and is based on false premises and certain misconceptions of the use of the facility and its equipment. This is not to say that the facility is above criticism. On the contrary, criticism is both necessary and warranted. It is apparant that the shelter is crowded and noisy and in general not the ideal working environment. It may, in fact, be found during complete performance tests that the existing shelter equipment is not compatible and that the facility does not perform in accordance with its requirements. New systems must be criticized, tested, and thoroughly scrutinized if the final product is to perform acceptably. A new system is designed, however, to fill a need or a gap in the operations capability of a particular using command. Certain performance criteria are specified and the new system is designed to meet these requirements. In the TSC-23 these requirements included such things as:

1. The ability to operate 24 hours a day.
2. The ability to simultaneously send and receive teletype messages on all channels.
3. The ability to operate under high message traffic load for limited periods of time.

Other imposing criteria included the requirements that the facility be assembled from current off-the-shelf equipment and that the shelter be readily transportable in existing aircraft. Criticism directed at the present facility design must take these factors into consideration if it is to be constructive, useful criticism. Air Force Communications Service originally set forth the requirement that this facility be equipped and designed to accommodate five operating personnel and that it be equipped with four teletype stations, each capable of full duplex operation. Most of the criticism has been aimed at reducing the manpower requirements by redesigning the shelter equipment layout for accommodation of only three operators. One suggested configuration and the existing configuration are shown in Figure 5-2. This design conception



A SUGGESTED CONFIGURATION -- THREE-MAN OPERATION



EXISTING CONFIGURATION -- FIVE-MAN OPERATION

FIG. 5-2 AN/TSC-23 EQUIPMENT CONFIGURATION

combines the switchboard and teletype control panels into one control sector and proposes operations using one crypto-teletype operator, one clear-teletype operator, and one switchboard operator (supervisor). The major advantage to this configuration is that it would permit more efficient operation under conditions of relatively low message traffic load. The configuration is based upon certain incorrect assumptions, however, and the major premises of the argument violate the facility requirements set forth by the using command. The inconsistencies include:

1. The assumption is made that full position manning is unnecessary due to the fact that communications centers do not normally transmit and receive simultaneously.
2. The assumption is made that scheduling and traffic load per unit of time will permit three-man operations and that periods of high traffic load can be handled with the suggested configuration.
3. The assumption is made that control and operate functions can be readily distinguished and separated.

The requirement for a five-man operation was set forth by the using command, and the existing design configuration was established on the basis of firm considerations. The operation of the TSC-23 does not lend itself to analysis involving drawing distinctions between operate and control functions, nor does it permit complete evaluation in terms of message flow through the shelter. The designations of supervisor and switchboard operator are somewhat misleading in that they connote control functions rather than operator function. The supervisor serves as a clear-teletype operator and determines the assignments of messages to the other teletype positions. He receives all hand-carried messages and screens individuals entering the facility. It is thus necessary that this position be located near the door and also near the switchboard. All monitoring functions can be monitored from the teletype equipment supplied. Each operator position is considered to be relatively independent of any other and no serial flow internal communication is imposed

The switchboard operator is responsible for receiving and routing all voice-radio communications and thus serves more in the capacity of a radio-operator than a switchboard operator. This operator will be quite busy under

conditions of high message load and is provided with a typewriter for recording messages which cannot be routed or which terminate in the facility.

The existing configuration lends itself quite well to operations requiring only three operators. Under low traffic load, the supervisor would serve as a clear teletype operator. The existing configuration would be superior to proposed three-man configurations under high traffic load since it would place less load on the potentially burdened switchboard operator. In high loading, the supervisor would handle teletype setup and assignment, thus allowing the switchboard operator to devote full attention to the routing, logging, and recording functions of his position.

3. WORKSPACE AND CONSOLE DESIGN

Operator workspace in the TSC-23 is restricted but not considered to be prohibitive for operation. This is a problem which should be resolved, however, in design of future facilities. Operators seated at console work stations should have at least 18 inches knee space for assurance of personal comfort. In the TSW-23, the available knee space ranges from 11 to 14 inches at the various consoles. The work area in front of a console should be approximately 32 by 32 inches for extended operation.

Depending upon the nature of the tasks performed, the width dimensions may be as low as 27 inches. All operator positions in the TSC-23 have a width dimension of at least 27 inches but are restricted in the depth dimension. Operators can be accommodated, but especially tall individuals will be required to execute some chair maneuvering when they sit down.

Maintenance workspace is restricted but not prohibitively so. Human engineering standards are not adequately met and future design should give consideration to this problem as well.

Informal discussions with AFCS operators revealed several criticisms of console design. Normally it is not good policy to ask highly-experienced operators to evaluate new equipment due to natural resistance to change on the part of these people. Some criticisms were made, however, concerning deviations from "conventional pratice" where there was no apparent need or reason to change from conventional practice. Such information is beneficial. In the

TSC-23, there was some confusion expressed by the operators concerning the patch panel above the cordless switchboard. Their main objections centered around the relative positioning of the MONITOR, EQUIPMENT, and LINE rows, and the labeling of the jack vertical columns.

a. In conventional practice, horizontal jack rows are labeled LINE, EQUIPMENT, MONITOR in that order. In the TSC-23, they are labeled in the exact reverse.

b. In conventional practice, vertical jack columns are labeled with number designations for channels within a particular radio. In the TSC-23, the channels are numbered on a consecutive basis (one through eight for active radios 1 and 2).

The desirability of changing these labels and jack positions will have to be pursued further during Category II testing before definite recommendations can be made.

Radio channel modulating indicator lights on the cordless switchboard are very bright and cause excessive glare when an operator is seated at this position. These lights have clear caps with convex lenses which direct the light in a beam toward the operator. These lens caps should be changed either to a frosted white cap or to a clear cap which would distribute the major portion of the light around the periphery of the lens.

4. PERSONNEL SAFETY

Several personnel safety hazards exist in conjunction with TSC-23 operation and steps should be taken for their correction prior to field and further test operation.

Warning and danger signs definitely should be used in regard to the log periodic antennas, the HF whip antenna, and the gas turbine exhausts. Due to the possible severity of injury from HF burns and electrical shock, accidental contact with the log periodic antenna should be prevented. This could be accomplished by surrounding each antenna with a one- or two-wire fence. In addition, warning signs should be placed at 30-40 foot intervals along the fence.

Energized circuits are exposed on the top of the black patch panel at the supervisor's console. This constitutes a hazard since inadvertent personal contact could occur. These circuits should be covered and properly insulated to avoid such contact.

SECTION 6

AN/TPS-35 RADAR SET

Like the AN/TPN-14, the AN/TPS-35 (Surveillance Radar Shelter) is designed with two tentative operator positions -- an alignment and test position and a maintenance repair area. The shelter is designed for surveillance radar control within a radius of 80 miles of the landing strip. Provided equipment includes a 10-inch PPI radar scope, UHF and VHF radio equipment, anti-jamming equipment, and radar IFF/SIF equipment. A microwave link and remote cabling provide the means of relaying the radar information to the Air Traffic Control Central AN/TSW-5.

General layout and operator work area in this shelter are adequate from a human factors standpoint. Air conditioning and ventilation, a problem in other shelters, appear to be quite good in the TPS-35. This is primarily due to the shelter design and the fact that most of the major heat-producing equipment is isolated from the operator work area by an acoustical wall of sliding panels.

The only major problem appearing at this time concerns the safety of personnel working in and around the shelter. Precautions are necessary to protect operating and maintenance personnel from the RF radiation produced by this radar equipment. A hazard exists at close range to the antenna because of the sheer energy of the RF output. Serious burns and possible death may result from being exposed to such RF energy at close range. Maintenance personnel should be provided with an externally-mounted switch for controlling the output of the radar. Once such a switch is thrown, there would be no danger of radiation injury should someone inadvertently turn the radar on while repairmen were close to the antenna.

Further precautions may be warranted in regard to this radar due to the fact that the frequencies radiating from the TPS-35 antenna are below 3,000 MC. The full effect of exposure to radio frequencies is not known. One relevant example of the effect of these frequencies is the occurrence of the RF hearing phenomenon. Certain radio frequencies will cause an inner ear reaction and an individual will actually "hear" tones. The RF hearing phenomenon is a function of peak power density at frequencies below 3,000 MC, and it occurs at

average power densities below the 0.01 w/cm^2 or "safe" level. It is known that this phenomenon will occur, but its implications from the standpoint of damage to the human ear have not yet been established.

SECTION 7

NOISE CONTROL MEASUREMENT

During the development of the AN/TSQ-47 System, there were considerable problems concerning the control of noise within the shelters and concerning the amount of noise that should be endured by the operators.

The primary reason for the concern over the noise is its effects upon speech communications. Only in a few instances is the noise at such a level as to be physiologically detrimental.

Because data related to speech communications are frequently given in Speech Interference Level (SIL), an attempt will be made to give an explanation in both SIL and the more conventional total sound pressure level.

1. SPEECH INTERFERENCE LEVEL

Because of the annoyance of interference with speech and also because noise interfers with work where speech communication is necessary, a noise rating based on the speech interference level is frequently useful. Noise interference with speech is usually a masking process. The background noise increases our threshold for hearing, and, as a result, we may hear only a few or perhaps none of the sounds necessary for satisfactory intelligibility.

The consonants contain most of the information in speech and unfortunately they are more readily masked than vowels. A number of experiments have shown that nearly all the information in speech is contained in the frequency region from 200 to 600 cps.

For reasons of simplicity, the speech interference level is the arithmetic average of the decibel level over-all of the noise in each of the octave bands 600 to 1,200 cps., 1,200 to 2,400 cps., and 2,400 to 4,800 cps.

It is important to note that in computing speech interference levels by the octave-band method, it is assumed the response frequency characteristics of all components of a speech communication system are uniform or substantially level. When frequency discrimination is appreciable, the SIL method should not be used. Also, this method may not be applicable if the noise is predominately in the frequency range below 600 or above 4,8000 cps.

The General Radio Sound Level Meter (this is not a spectral distribution analyzer) can be used to indicate a frequency shift to the low side. The instrument has three scales, "A," "B," and "C". For most readings, the "C" scale is used because it has a rather flat response from 20 to 20,000 cps. However, when all three scales are used and the readings on the "C" scale are at least several (3) decibels greater than the readings on the "A" and "B" scales, this indicates that much of the noise is probably below 600 cps.

Speech interference levels (in db re. 0.0002 microbar) should be less than the values given in Table 7-1 in order to have reliable conversation at the distances and voice levels shown.[1, 2]

TABLE 7-1

SIL'S FOR VARIOUS DISTANCES

Distance Feet	Voice Level: Normal	Raised	Very Loud	Shouting
0.5	71	77	83	89
1.0	65	71	77	83
2	59	65	71	77
3	55	61	67	73
4	53	59	65	71
5	51	57	63	69
6	49	55	61	67
12	43	47	55	61
24	37	43	49	55

It is not recommended that the last two columns be used because when the voice is very loud or shouting, additional distortion to intelligibility is introduced and, thus, the last two columns could be misleading.

The speech-interference level can also be used to predict the usability of a telephone line under given noise conditions. The following schedule has been found satisfactory when an F-1 Western Electric handset is used.

[1] Harris, C. M.; Handbook of Noise Control, McGraw-Hill Book Company, 1957.

[2] Peterson, A. P. G. and Gross, E. E.; Handbook of Noise Measurement, General Radio Company, 1960.

SPEECH INTERFERENCE LEVEL	TELEPHONE USE
Less than 60 db	Satisfactory
60 to 75 db	Difficult
Above 75 db	Impossible

2. SOUND PRESSURE LEVEL

Noise can influence work output in many ways. Researchers have found that the effects of noise on work output depend greatly upon the nature of the work; a long-term job requiring constant vigilance (such as radar surveillance) is especially susceptible. The effect of noise is more likely to be a higher rate of errors and accidents than an actual reduction in total output. High-frequency audible sounds are likely to contribute more to worker fatigue and errors, whereas low-frequency sounds are more masking to communications.

For this reason, no simple statement concerning the effects of noise can be made. It can be misleading to present criteria for maximum noise levels in just total sound pressure level. It may be necessary to establish limits within certain broad spectral bands.

Because high-frequency sounds (above 2,000 cps) are usually more annoying than are lower frequency sounds of the same sound pressure level, it may be necessary to make a considerable effort at reducing these levels.

Another effect of noise concerns localization of sound. When a work area has acoustically hard walls, floor, and ceiling, the room is "live" -- reverberant. The noise is reflected back and forth, and the operators are immersed in noise with the feeling that it comes from everywhere. When the work area is treated with absorbing material, the reflected sounds are reduced and the operators feel that the noise is coming directly from the equipment. This localized sound seems to be less annoying.

Tentative criteria for noise control have been arrived at and confirmed by experiments and field tests. "Under 45 db, one can carry on a relaxed conversation at 10 or 20 feet with a low voice. This level is desirable for private offices and conferences. At 55 db, conversation is intelligible at a distance of several feet with normal or raised voice, a desirable upper limit

for business offices. Speech communications are difficult at 65 db but may be acceptable for general factory spaces. At 75 db, communications are marginal although danger signals can be shouted and heard within a few feet. If speech communication is necessary in the work setting, anything above 75 db would not be acceptable."[1]

The sound pressure level in the various shelters is as follows:[2]

TABLE 7-2

SPL'S FOR THE AN/TSQ-47

AN/TSW-5 IFR Shelter	Positions 1, 2, 3, 7, 8 & 9	79 db
	" 4	80 db
	" 5 & 6	81 db
A/G/A Shelter	Maintenance Position	89 db
AN/TSW-6 Tower Shelter	Positions 1, 2 & 3	77 db
AN/TPN-14 PAR Shelter	Operator Position	82 db
	Maintenance Position	84 db
AN/TSC-23 Communications Shelter	Center of Shelter	86 db
AN/TPS-35 Radar Shelter	Operator Position	82 db
	Maintenance Position	82 db

3. NOISE CONTROL

Since the sound pressure level in the shelters was in excess, it seems appropriate to present a discussion on noise control and attenuation. The noise in the shelters comes from various sources, and no one thing can provide the necessary attenuation. Therefore, it would be advantageous to discuss each of the several sources of noise.

[1]McFarlane, R. A. Human Factors in Air Transportation. McGraw Hill Book Company, 1953.

[2]These data were recorded during Qualification Testing of the AN/TSQ-47 System at Fort Devons, Mass.

a. <u>Heating and ventilating system noise.</u> This heating and ventilating system generates noise in several ways. The blower-blade frequency (number of blades passing a fixed point per second) and its harmonics will be present as noise. Also, the high velocity of the air flow through the ducts, plenum, grilles, etc., causes noise.

Blowers and their driving motors should be mounted on a base weighing about three times the combined weight of the motor and blower. The base should be isolated from the floor with vibration isolators. The outlet of a blower must be connected to the plenum or ducts by means of a flexible canvas collar.[1] Conic flow, low-pressure attenuators are available which can be put in series with the air ducts that will significantly decrease the blower noise (6 to 15 db).

The noise resulting from air turbulence is strongly dependent on the flow velocity in the duct. The intensity of aerodynamic noise may depend on the fifth power of the velocity and in some cases on as high as the eighth power of the velocity. Thus, doubling the areas of the duct or plenum and maintaining constant volume flow will reduce the aerodynamic noise by 15 to 24 db.

If the walls of the plenum and ducts are covered with a sound-absorbing material, attenuation of several decibels per foot may be obtained. The noise loss is proportional to the perimeter of the linings, and the total energy flux in the wave is proportional to the cross-sectional area of the duct; hence, the attenuation is proportional to the perimeter divided by the cross-sectional area.

The attenuation in a lined duct may be computed from the following empirical formula:

$$\text{Attenuation} \quad 12.6\,\frac{P}{A}\,\alpha^{1.4} \quad \text{db/ft.}$$

where P=perimeter in inches
A=cross-sectional area, square inches
α =absorption coefficient for liner material

[1]Most of this discussion is taken from the: <u>Handbook of Noise Control.</u> Harris, C. M.

Noise is generated at the outlet grilles which is strongly velocity dependent. A problem arises in the use of grilles because if the face velocity of a grille is held constant, the total sound power radiated increases in proportion to the area of the grilles. Thus, each time the grille area is doubled, the sound level in the room increases 3 db.

The location of the grilles can result in some reduction in the nosie level. Locations near the center of the ceiling are to be preferred from the standpoint of noise suppression. The next most favorable position is near the center of the edge where wall and ceiling join and as much below the ceiling level as is practicable. The worst position is in a corner at ceiling level. The difference between the best and the worst positions may be as much as 6 db.

The pressure drop associated with bends in air ducting is less for bends with a radius of curvature which is large. The pressure drop associated with short bends results in additional aerodynamic noise. If abrupt bends are necessary, both the pressure drop and the noise may be reduced by the use of turning vanes. These turning vanes usually require the addition of vibration-damping material.

b. Wall Construction. The transmission of noise into a shelter can take place by airborne noise passing through the walls and by transmission of vibration in the shelter structure caused by mechanical vibration imparted directly to it. (This vibration may cause a wall or floor to vibrate and to radiate sound.)

Available data suggest that the shelter walls for the AN/TSQ-47 system will not attenuate exterior noise by more than 6-8 db. This is inadequate, especially considering the noise the AN/TSW-6 (Tower) will be subjected to during the landing and taking off of aircraft.

The mass law can be used to estimate the transmission loss of several layers of glass separated by a small airspace (less than 1/2 inch). For windows with two layers of glass separated by a relatively large airspace (equal to or greater than 1 inch), the average transmission loss is estimated to be about 3 db greater than the mass-law value, provided the two layers of glass are structurally insulated from each other (resilient material such as neoprene rubber is good). Some benefit may be obtained by selecting panes of different thicknesses so that their resonant frequencies will differ.

Some typical transmission losses for double glaze windows are:

38 db loss using two 1/4" glass panes separated by 1/2" air.
45 db loss using two 1/4" glass panes separated by 6" air. [1]

Another advantage to using double glazing is the heat transmission factor. Double glazed windows have a U factor of 0.55 as compared to 1.13 for single glazing.

An effective way of obtaining a large amount of sound insulation of a given weight per unit area is by means of double-wall construction (i.e., no mechanical connection between the two sets of walls, nor the wall structural supports). If the inside and outside walls are isolated from each other by separators and gasketing, it would be possible to realize a 30-40 db attenuation through the shelter wall. A problem encountered in the present AN/TSQ-47 system fabrication was the use of bolts and flanges for conduit and duct openings. These provided a significant amount of metal-to-metal contact of the outside wall with the interior. Thus, good acoustical pathways were established for sound transmission.

Almost all the major pieces of equipment within the shelters (communications sets, radar receivers and transmitters, displays, microwave equipment and associated power supplies) have blowers connected with them. For this reason, considerable care needs to be taken to assure that isolation mountings are employed for the blower housings. Also, considerable attention should be paid to the type of blower used, the blower-blade frequency, and the means of distributing the air around and through the equipment. It would probably be advantageous to duct part of the air supply from the central air conditioner around the equipment and then directly back to the air conditioner, thus eliminating the need for all the separate blowers which are noise-generating devices.

---

[1] Harris, C. M.; op. cit.

SECTION 8

AUXILIARY CONDITIONS

To enhance the system's operation, several other facilities should be considered. Also, other aspects common to all the shelters must be considered. This final section is devoted to a presentation of data in these areas.

1. MAINTENANCE FACILITY

Two previous technical reports (ESD-TDR-63-302 and ESD-TDR-63-326) analyzed the AN/TSQ-47 system requirements and established the need for a centralized maintenance shelter to complement the existing maintenance areas in the operational shelters (AN/TPS-35, AN/TPN-14, AN/TSW-5, etc.). From studies conducted to date, it would appear that a maintenance facility could primarily serve the following functions: (a) maintenance storage function--spare parts for the operational shelters in which there is limited storage space could be stored in the maintenance facility; (b) maintenance coordination function --the maintenance facility could act as the main inventory control area for the whole AN/TSQ-47 system and as the emergency base maintenance dispersing area; and (c) maintenance work area function--several of the shelters have limited maintenance repair area for serving the entire system.

2. PROFICIENCY FACILITY

A previous technical report (ESD-TDR-64-179) analyzed the requirements for a proficiency facility. The results of this study indicate that the nature of present mobile squadron operations demonstrates the need for a proficiency facility, as described in the aforementioned report, in a squadron-level training program. The use of a proficiency facility should result in a high rate of learning and positive transfer in air traffic control operations. This facility, in conjunction with the AN/TSW-5 RAPCON shelter, would be capable of simulating and quantitatively measuring a broad category of terminal ATC operations.

3. VENTILATION, HEATING, AND AIR CONDITIONING

a. <u>AN/TSW-5, IFR Shelter.</u> Present calculations indicate that the IFR shelter will be satisfactory during cold-weather operation. A problem is indicated in the air conditioning under the extreme outside ambient condition

of a dry bulb temperature of 125 degrees F. and a wet bulb temperature of 75 degrees F. Because of the location of some of the heat-producing equipment within this shelter, there is likely to be an uncomfortable spread of ambient temperature for the three operators at the Feeder and two PAR positions. The temperature of the air around these operators' heads could be 20° cooler than around their feet. This shelter will be difficult to cool or heat evenly because of the air plenum limitations with respect to the expandable sides. The shelter layout prohibited the packaging of equipments so that the heat-producing equipments could be isolated to the outlet side of the airflow cycle within the shelter.

The maximum fresh air obtainable from one air conditioner is 75 CFM. With nine operators requiring 25 CFM/person and two air conditioners, the amount of available fresh air is less than optimal.

b. AN/TSW-5, A/G/A Shelter. This shelter should be satisfactory during cold-weather operations. This shelter will be uncomfortable for an operator spending a prolonged period of time within the shelter during high external temperatures (125 degrees F.). The air velocities around the work bench in the operator comfort zone (1 ft. from the floor to 6 ft. from the floor) are likely to vary from 50 ft./min. to 110 ft./min. Likewise, the air temperature in this same zone is likely to vary considerably. Thus, the operator is likely to feel drafty and experience an uncomfortable temperature variation between his neck/head region and his feet.

c. AN/TSW-6. The data indicate that the temperature and airflow will be satisfactory during cold-weather operations. During high external temperature operations (125 degrees F.), the air velocity is expected to be comfortable in the vicinity of personnel (25 to 55 ft./min.). Under these conditions, the air conditioner will provide, for the operators, air close to the upper limit of the personnel comfort zone (79 degrees -- ASHRAE Guide and Data Book, 1961). With three operators in this shelter, each requiring 25 CFM of fresh air to remain comfortable, the 75 CFM limitation of the air conditioner will be adequate.

d. AN/TPS-35. The arrangement of equipments within the AN/TPS-35 shelter is such that the major heat-and noise-producing equipments are isolated behind acoustical panels and on the outlet side of the airflow cycle. This means that conditioned air will pass the personnel before it passes equipment. No data

were available concerning actual calculations on air velocity and effective temperatures within the operational zone during either the heating or cooling cycles. Because part of the airflow will be directly ducted to the equipment at the rear of the shelter and part of the conditioned air will be provided at the operator control zone before passing over equipment, it is expected that the heating, cooling, and airflow will be satisfactory.

e. AN/TPN-14. The location and design of the ventilation system within this shelter should provide a satisfactory airflow through the shelter. It is possible that a person standing at the left end of the work bench, so that his hand is relatively close to the perforated surface of the air plenum, will experience an uncomfortable draft on his face.

The air outlet duct to the air conditioner is located on the back wall of the shelter behind the radar transmitter. The position of the transmitter is a function of the required operating position of the antenna. The transmitter has a blower in it that provides the necessary circulation to cool its various components. It is improbable that the antenna/transmitter will be positioned so that the airflow through the transmitter blower will be compatible with the normal direction of the airflow through the shelter. It is probable that the transmitter blower will cause the heat from the transmitter to mix with the overall shelter air and cause an increase in the temperature of the personnel ambient air. The capacity of the air conditioner will probably be marginal for maintaining an effective temperature within the operator comfort zone under conditions of maximum dissipation of electric power and maximum ambient temperature of 125 degrees F.

f. AN/TSC-23. No calculations concerning actual air temperature under the extremes of hot and cold weather and of the airflow rate within the shelter have been made to date. Since the pressure drop through the shelter was anticipated to be more than desirable, a booster fan was installed in series with the shelter airflow. This fan is located below a KW-26 receiver and power supply on the rear left side of the shelter. This auxiliary blower should decrease the air pressure drop through the shelter, and, if properly ducted, prevent some of the heat from the transmitter and power supplies from mixing with the incoming air. Otherwise, these equipments would raise the air temperature for the personnel within the shelter.

4. POWER GENERATORS AND AIR CONDITIONERS

At least three problems arise in connection with the use of these equipments. The overall noise level from the generators and air conditioners (in excess of 90 db.) is such as to cause hearing damage if an operator or repairman were to stay in the immediate area of this equipment for any length of time. It is recommended that ear protectors be provided for personnel to wear if and when they might be working around this equipment for extended time periods.

Warning notices should be placed around the generators. The spare generators are, in most cases, automatically turned on when a fault develops in one of the operating generators. If a person were to be standing in the exhaust area of a generator when it is turned on, serious injury may result

The weight of the generators exceeds the weight that four enlisted personnel should carry safely. Only four carrying handles are provided at the corners of the generators. It is recommended that two lifting bars be attached to the two long sides to enable up to six persons to aid in lifting and carrying the generators during assembly and disassembly operations.

DISTRIBUTION LIST, AF19(628)-439

ACTIVITY	NO. COPIES
Hq.ESD (ESRRG) L.G.Hanscom Field, Bedford, Mass.	8
Hq.ESD (ESTI) L.G.Hanscom Fld.,Bedford, Mass.	22*
Hq.ESD (ESRR) L.G.Hanscom Fld.,Bedford, Mass.	1
Hq.TAC (DCE) Langley AFB, Va.	1
TACSO/Major Dow, L.G.Hanscom Fld.,Bedford, Mass.	1
Hq.AFSC (SCSEW) Andrews AFB, Wash.25,D.C.	2
Hq.TAC (DORQ) Langley AFB, Va.	2
Hq.USAF (AFORQ) Wash. 25, D. C.	1
Hq.TAC (DOC) Langley AFB, Va.	2
Hq.ESD (ESRHA) Mr. Begley, L. G. Hanscom Fld.,Bedford, Mass.	1
ATTSC/Major Worthington, L. G. Hanscom Fld., Bedford, Mass.	1
AFLC (MCFC) Mr. Deering, L. G. Hanscom Fld., Bedford, Mass.	1
Hq.AFCS (CSXPRT) Scott AFB, Ill.	2
USARDL (SIGRA) SL-ADT/Tech. Dec. Ctr., Ft. Monmouth, N.J.	1
Dept. of Navy, NATC (NAMEP Sr. Officer) Patuxant River, Md.	1
Hq.AFCS (FFRE) Scott AFB, Ill.	2
AUL, The Air University, Maxwell AFB, Ala.	1
RADC (RYLD/Doc Library), Griffiss AFB, N.Y.	1
ASD (ASAFRD Dist.), W-PAFB, Ohio	2
USA Elec. Proving Ground (Tech. Library), Fort Huschuco, Ariz.	2
Hq.USAF (AFOOP), Wash. 25, D. C.	1
Hq.USAF (AFMMP), Wash. 25, D. C.	1
USN Electronics Lab.,San Diego,Calif.	1
Hq.USAF (AFSSA), Wash. 25, D. C.	1
USARDL (SIGRA/SL-SUC), Ft. Monmouth, N.J.	1
Dept. of Navy, BUShips, 9670/12. Ser 68B7A-299/Mr. Loeb, Wash. 25, D. C.	1
Director, USN Research Lab., (Tech Library) Wash. 25, D.C.	2
Dept. of Navy, Director, Avionics Div. (AW), BuAer, Wash. 25, D.C.	1
Det. 1, 1800 Supp. Sq. (AFCSRO), L.G. Hanscom Fld., Bedford, Mass.	2
Dept. of Army, Office of Chf. Signal Officer, SIGRD, -4a-2, Wash. 25, D. C.	1
NASA (Attn: Library) 1520 H. Street, N.W. Wash. 25, D.C.	1
Director, Langley Research Center, NASA, Langley AFB, Va.	1
USAF Missile Dev. Center (MDGRT), Holloman AFB, New Mexico	1
The Rand Corp. (USAF Liaison Off.) 1700 Main Street, Santa Monica, Calif.	1
Hq.ESD (ESST), L.G. Hanscom Fld., Bedford, Mass.	1
AFCRL (CRIP-A), OAR, USAF, L.G. Hanscom Fld., Bedford, Mass.	3
TOTAL	75

*ESD (ESTI) will accomplish distribution of report of DDC.

UNCLASSIFIED
Security Classification

DOCUMENT CONTROL DATA - R&D		
(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (Corporate author) HRB-Singer Inc., State College, Pennsylvania		2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A
3. REPORT TITLE A Human Factors Review of The AN/TSQ-47 Air Traffic Control/Communications System		
4. DESCRIPTIVE NOTES (Type of report and inclusive dates) None		
5. AUTHOR(S) (Last name, first name, initial) Busch, Allen C. King, Robert B.		
6. REPORT DATE Jun 64	7a. TOTAL NO. OF PAGES 53	7b. NO. OF REFS 0
8a. CONTRACT OR GRANT NO. AF19(628)439 b. PROJECT NO. 482L c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) HRB-Singer No. 353-R-6 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) ESD-TDR-64-446	
10. AVAILABILITY/LIMITATION NOTICES Qualified Requesters May Obtain Copies From DDC.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY 431L/482 Systems Program Office, ESD, L.G. Hanscom Field, Bedford, Mass.	

13. ABSTRACT

Category I testing has recently been completed on the AN/TSQ-47 Mobile Air Traffic Control/Communications Systems. This report presente a review of human factors problems which occurred during the Category I testing phase and in prior development phases of the system. The design changes suggested are based on recommendations made prior to the completion of Category I testing for the purpose of outlining tentative system deficiencies. Each shelter is reviewed separately, and problems common to all system facilities are discusse d. The Major topics of review are the operational considerations for each shelter, the working environment, and the design of concoles and work places.

DD FORM 1 JAN 64 1473

UNCLASSIFIED
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Communication Systems Control Systems Air Traffic Radar Design Human Engineering Human Factors						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2*a*. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2*b*. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7*a*. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7*b*. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8*a*. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8*b*, 8*c*, & 8*d*. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9*a*. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9*b*. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.